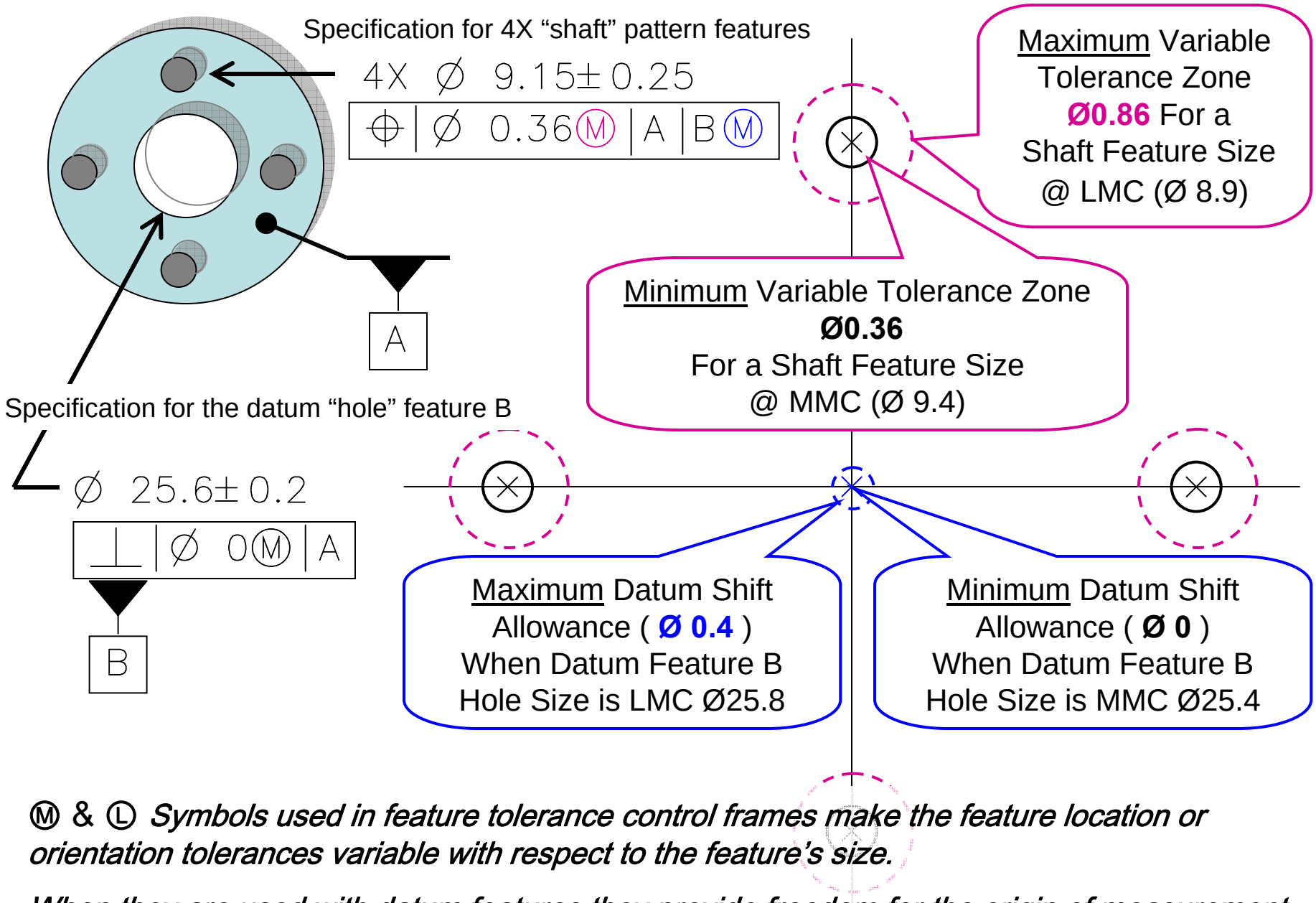
Pattern Inspection with Variable Geometric Tolerance Limits

From Disregarding to Fully Applying
Variable Feature Bonus and Datum Shift
Tolerances in a Pattern Inspection

By Paul F. Jackson



Ⓜ & Ⓛ *Symbols used in feature tolerance control frames make the feature location or orientation tolerances variable with respect to the feature’s size.*

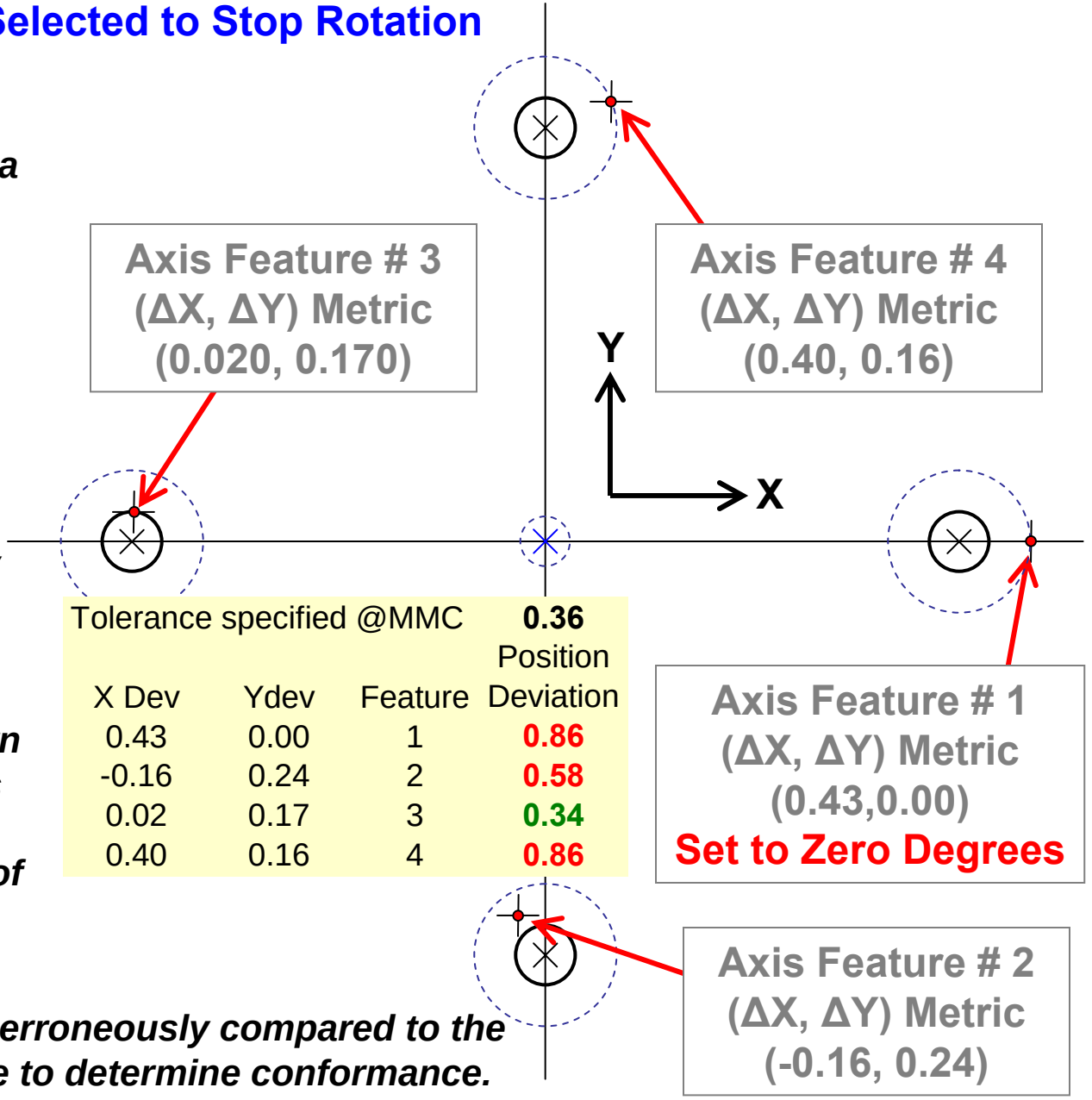
When they are used with datum features they provide freedom for the origin of measurement to shift or rotate with respect to the size of the datum features.

Pattern Fitting

Single Pattern Feature Selected to Stop Rotation

Rudimentary pattern inspections are often performed by establishing a coordinate reference coincident with the intersection of the datum feature's planes, axes, or center-planes.

In this example where rotation about the axis B is unconstrained by a tertiary datum feature one of the pattern features is often aligned to the coordinate system stopping the pattern rotation. Then the feature's coordinate deviations are use to figure the diameter of the position deviation.



Tolerance specified @MMC **0.36**

X Dev	Ydev	Feature	Position Deviation
0.43	0.00	1	**0.86**
-0.16	0.24	2	**0.58**
0.02	0.17	3	**0.34**
0.40	0.16	4	**0.86**

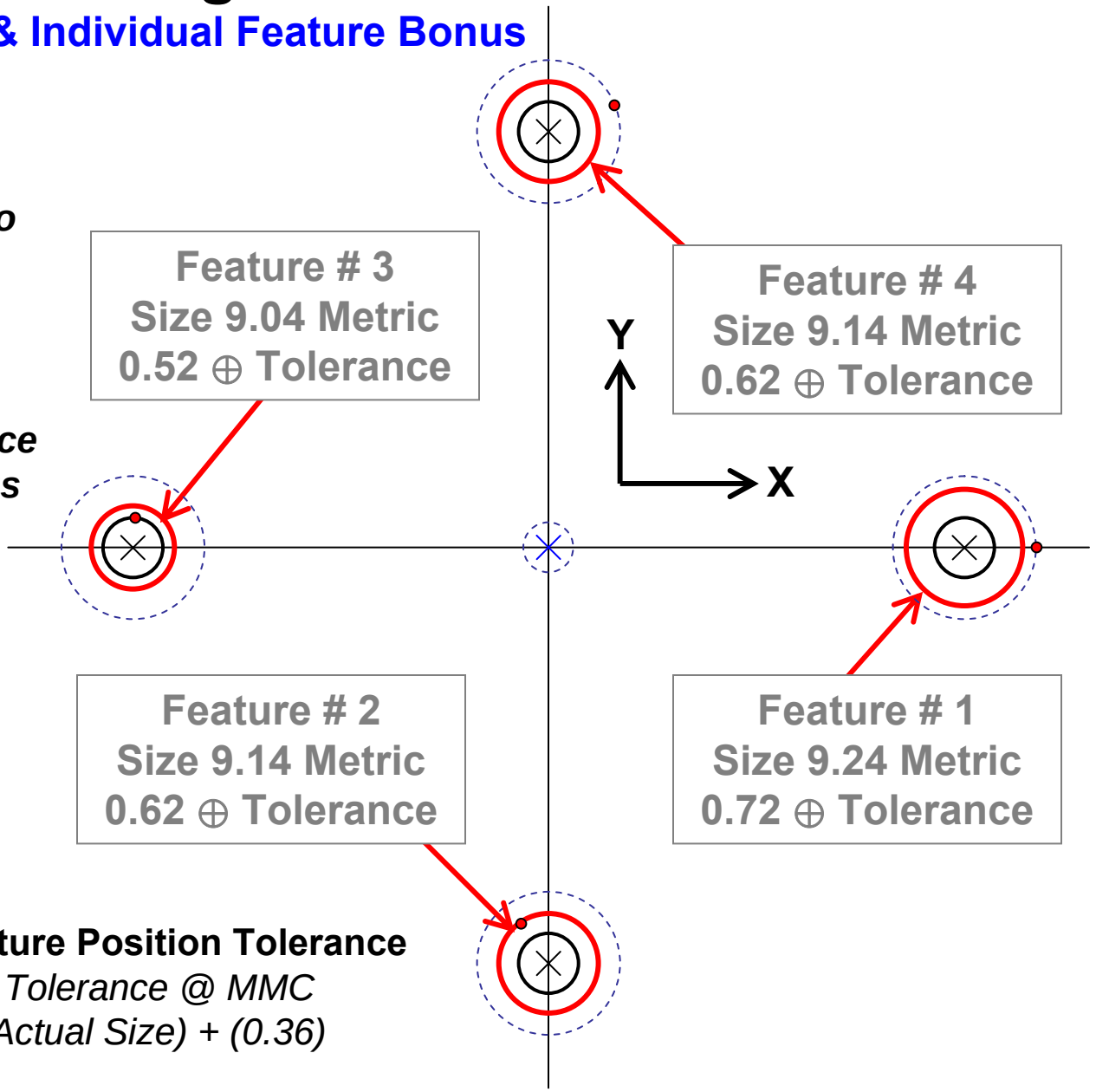
Those deviations often are erroneously compared to the minimum variable tolerance to determine conformance.

Pattern Fitting

Single Feature Rotation & Individual Feature Bonus

Coordinate Measuring Machines are often used to collect both size and location of individual features. Most CMM programs will figure the variable portion of tolerance (often referred to as bonus tolerance) and compare each feature's actual variable tolerance to the position deviation.

See the next slide for the analysis results.



Allowable Individual Feature Position Tolerance

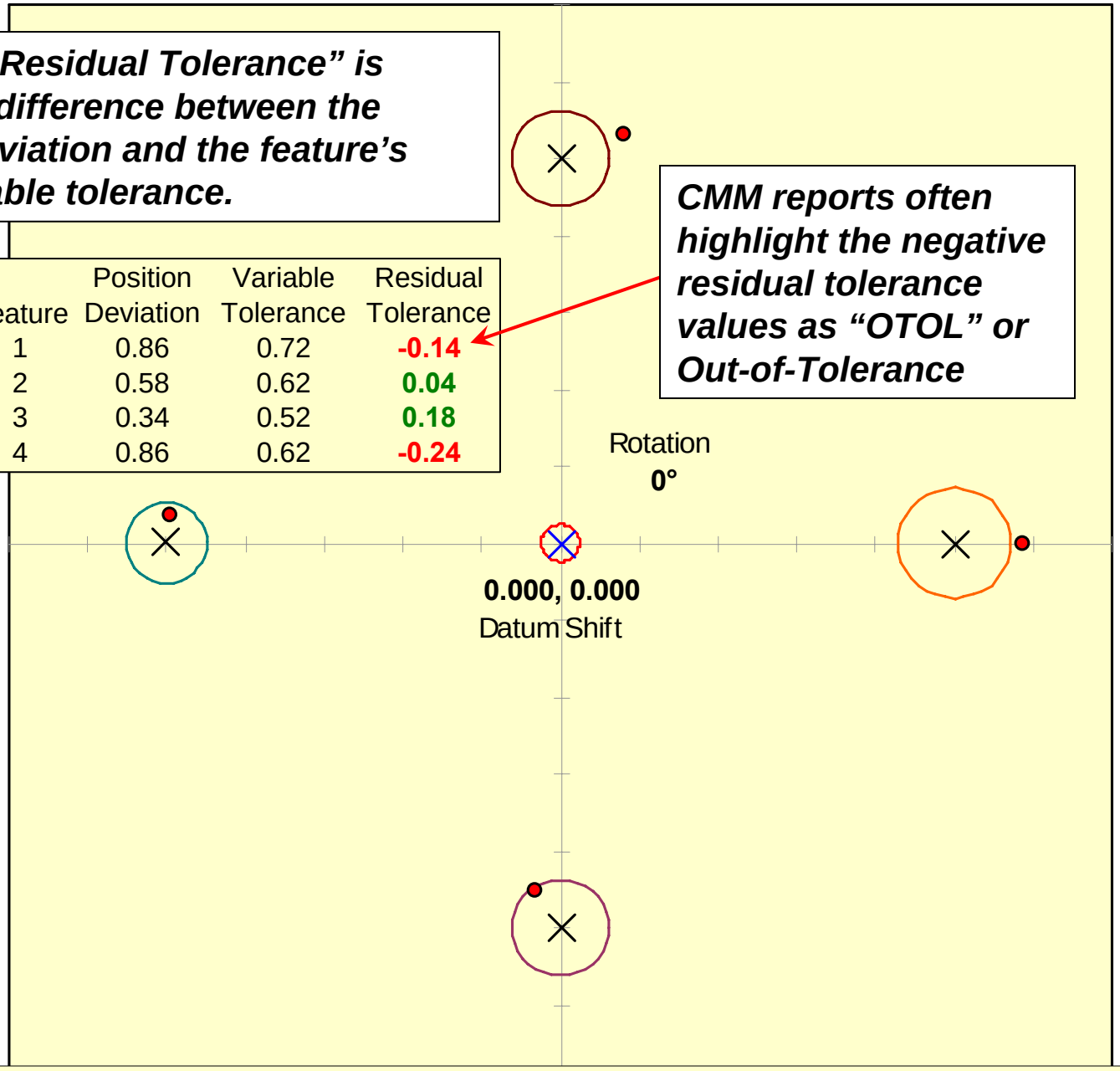
= Individual Bonus + Tolerance @ MMC

= (MMC Size (9.4) – Actual Size) + (0.36)

The value "Residual Tolerance" is simply the difference between the position deviation and the feature's actual variable tolerance.

X Dev	Ydev	Feature	Position Deviation	Variable Tolerance	Residual Tolerance
0.43	0.00	1	0.86	0.72	**-0.14**
-0.16	0.24	2	0.58	0.62	**0.04**
0.02	0.17	3	0.34	0.52	**0.18**
0.40	0.16	4	0.86	0.62	**-0.24**

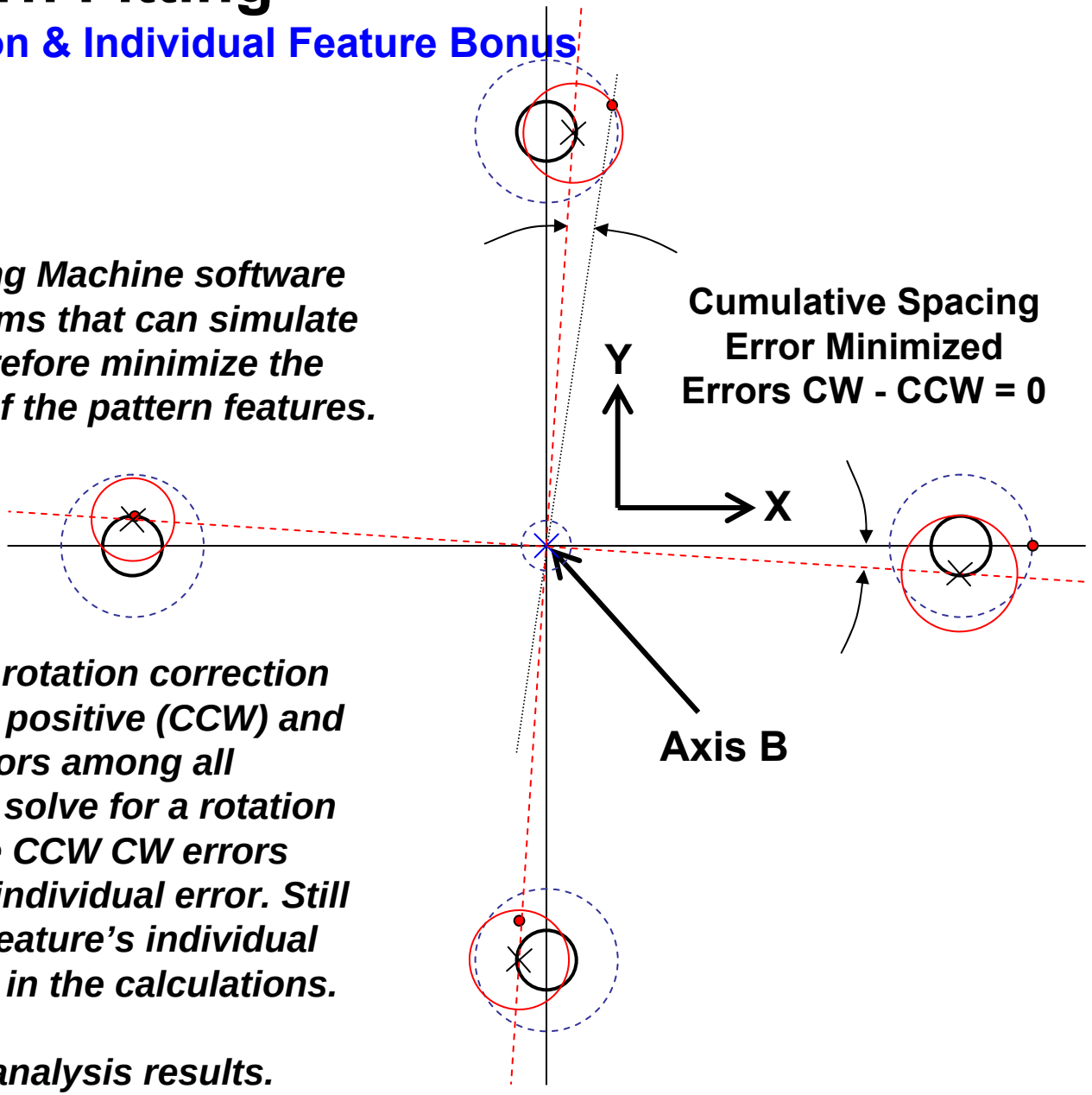
CMM reports often highlight the negative residual tolerance values as "OTOL" or Out-of-Tolerance



Pattern Fitting

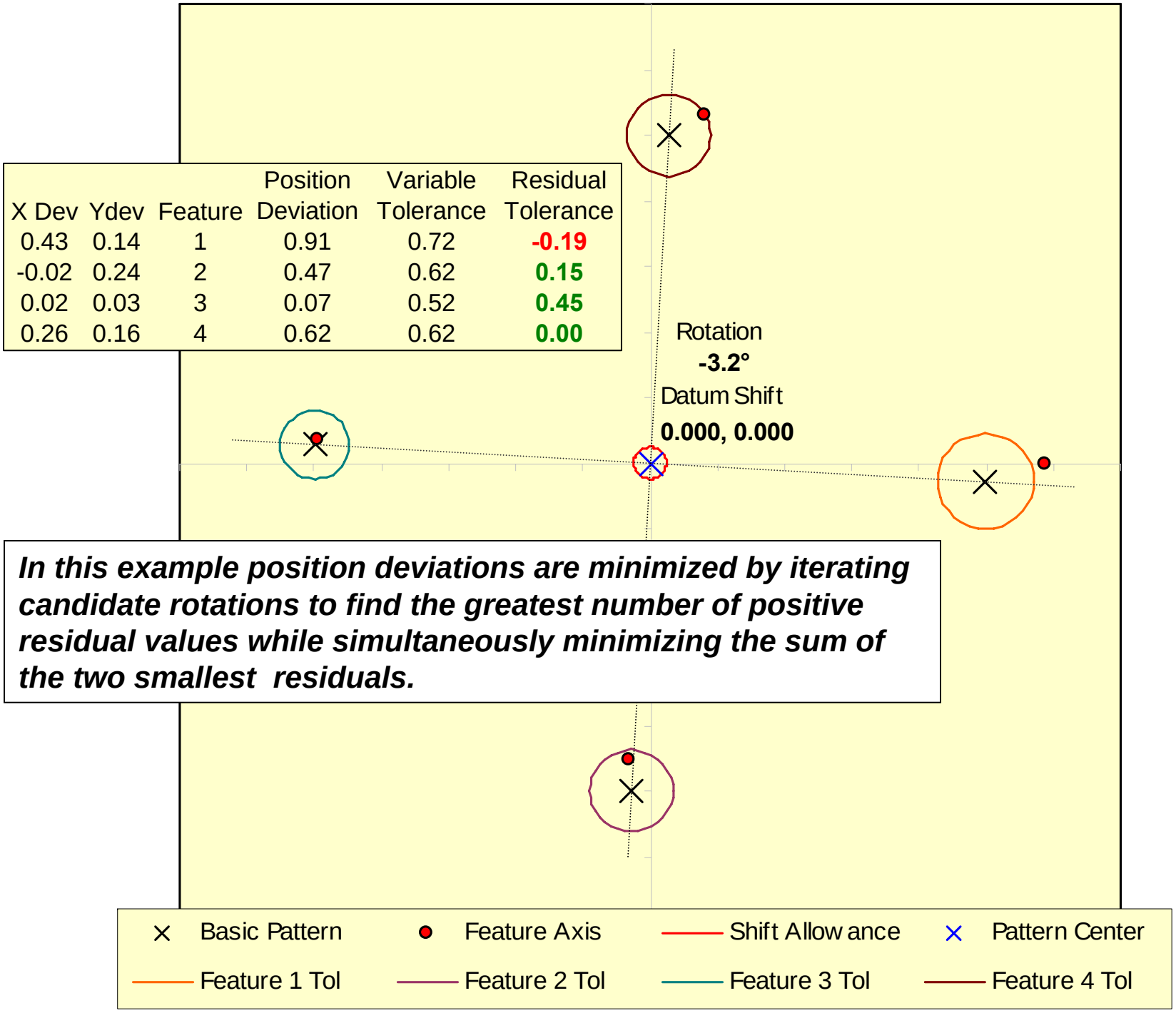
Multiple Feature Rotation & Individual Feature Bonus

Most Coordinate Measuring Machine software packages include algorithms that can simulate a pattern rotation and therefore minimize the computed position error of the pattern features.



Some routines solve for a rotation correction that makes the sum of the positive (CCW) and negative (CW) rotation errors among all features zero. Others may solve for a rotation that equalizes the extreme CCW CW errors minimizing the maximum individual error. Still others may include each feature's individual variable bonus tolerances in the calculations.

See the next slide for the analysis results.


X Dev Ydev Feature Position Deviation Variable Tolerance Residual Tolerance
0.43 0.14 1 0.91 0.72 -0.19
-0.02 0.24 2 0.47 0.62 0.15
0.02 0.03 3 0.07 0.52 0.45
0.26 0.16 4 0.62 0.62 0.00
Rotation
-3.2°
Datum Shift
0.000, 0.000
In this example position deviations are minimized by iterating candidate rotations to find the greatest number of positive residual values while simultaneously minimizing the sum of the two smallest residuals.
Basic Pattern
Feature Axis
Shift Allow ance
Pattern Center
Feature 1 Tol
Feature 2 Tol
Feature 3 Tol
Feature 4 Tol

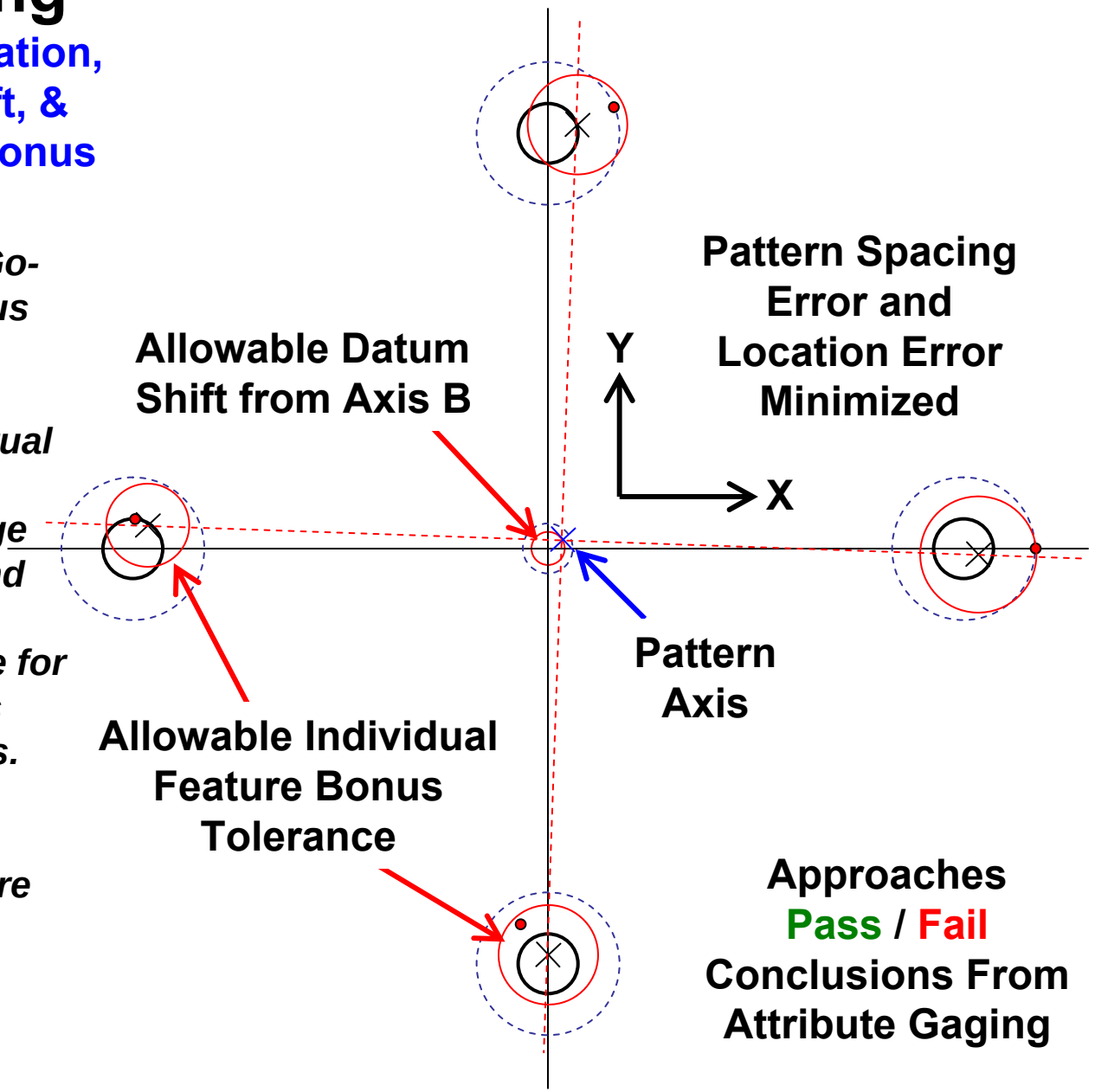
Pattern Fitting

Multiple Feature Rotation, Pattern Datum Shift, & Individual Feature Bonus

Attribute gages (Position Go-Gages) apply variable bonus tolerances physically by verifying fit of all feature's simultaneously to their virtual conditions. Wiggling and rotating the part on the gage iterates candidate shifts and rotations that utilize all available variable tolerance for datum and pattern features relative to their actual sizes.

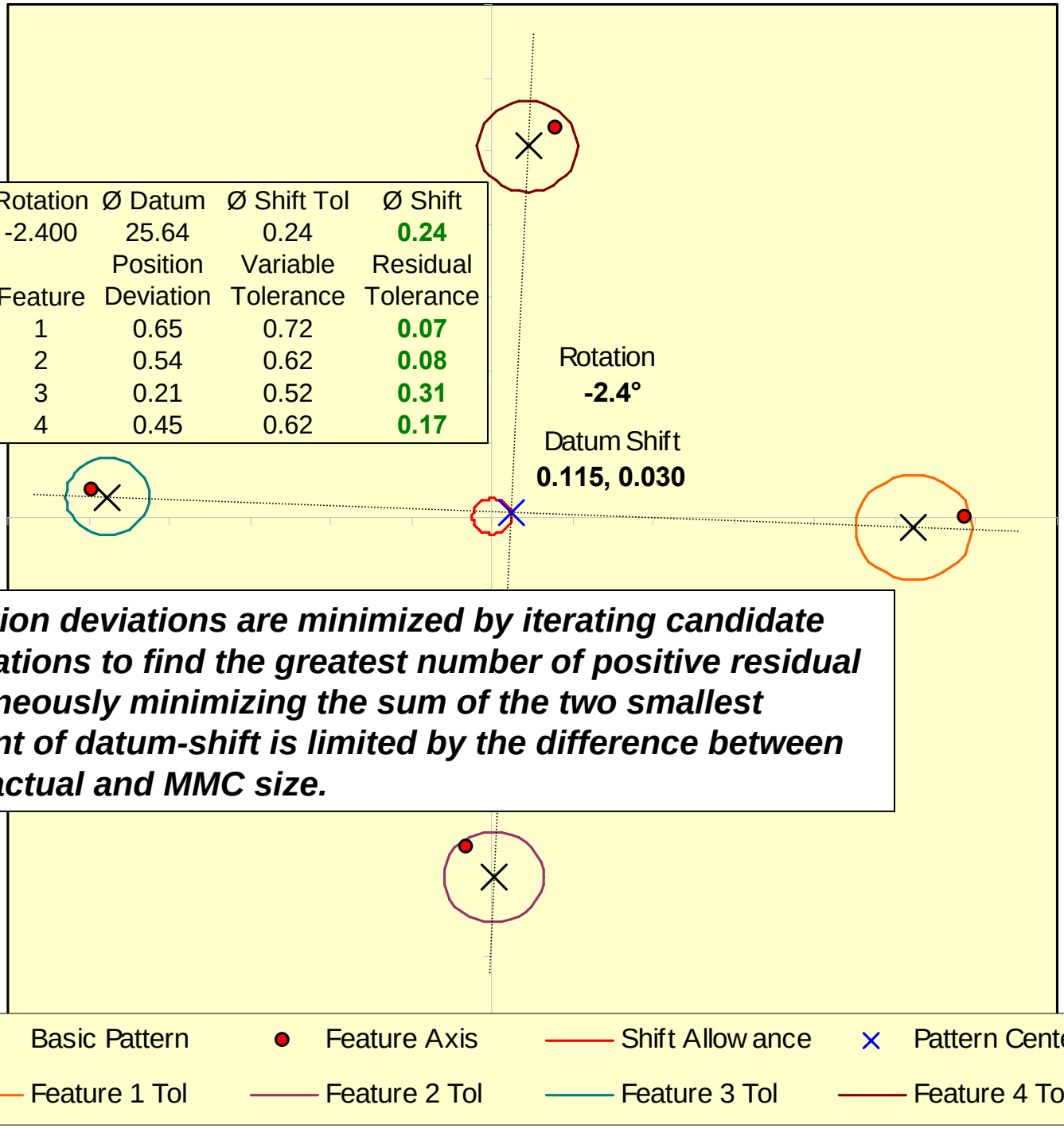
Very few Coordinate Measuring Machine software packages are capable of performing this analysis.

See the next slide for the analysis results.



Translation X	Translation Y	Rotation	Ø Datum	Ø Shift Tol	Ø Shift
0.115	0.030	-2.400	25.64	0.24	**0.24**

X Dev	Ydev	Feature	Position Deviation	Variable Tolerance	Residual Tolerance
0.32	0.07	1	0.65	0.72	**0.07**
-0.17	0.21	2	0.54	0.62	**0.08**
-0.10	0.04	3	0.21	0.52	**0.31**
0.18	0.13	4	0.45	0.62	**0.17**



In this example position deviations are minimized by iterating candidate datum-shifts and rotations to find the greatest number of positive residual values while simultaneously minimizing the sum of the two smallest residuals. The amount of datum-shift is limited by the difference between the datum feature's actual and MMC size.

Notes / Cautions

- Simultaneous Requirements Datum-shifts must be applied in a single common magnitude and direction to all drawing features whose feature control frames declare the same modified datum features in the same order. The CMM programming option to include datum shift tolerances for individual feature conformance should be disabled unless the shift is applied as described above.
- Continuous vs. Discreet At best rigorous continuous data analysis techniques of variable tolerances can only approach what is physically possible with attribute gaging because assumptions are made in data acquisition about the individual feature's form, orientation, and location.

Dilemma

- Process capability estimations differ greatly between inspections done with discreet data (attribute gaging) and those done with continuous data (variables gaging). Continuous data capability estimations are commonly preferred over demanded over discreet data capability estimations because the sample sizes required to make the estimations are dramatically different.

  This is the dilemma, even though continuous data capability estimations are preferred, they greatly underestimate conformance of process features that have variable tolerance limits because the variable “bonus” tolerance is excluded from the capability estimation formulas. The capability formulas require constant tolerance limits and are not designed to handle a variable tolerance limit. Attribute gages, on the other hand, verify fit to the variable limit boundaries and therefore do include the variable bonus in the capability estimation but their use is often prohibited because of the number of samples needed to requirements.